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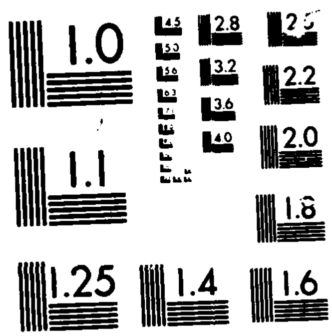

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Radargrammetric techniques, developed to support stereo mensuration and data capture from synthetic aperture radar (SAR) imagery, have been extended to enable map-to-image correspondence for computer-assisted radar image analysis. This mechanism projects existing digital map data into the image space of a new SAR image rigorously accounting for the sensor imaging geometry and terrain configuration.

Prerequisites for SAR map-to-image correspondence include (1) an analytical—

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sensor model, (2) recovery of the image acquisition parameters and (3) three-dimensional (3d) digital map data. Analytical radar mappingg techniques address the first two issues. Suitable 3d planimetric map data can be compiled directly from stereo photography using analytical plotters or indirectly using elevation data interpolated from digital elevation models to augment conventional two-dimensional map data derived from manuscripts.

The approach is illustrated by selected examples from a case study conducted for a test area near Freiburg, West Germany. Here, 3d digital data for transportation and landcover maps were assembled from cartographic sources using planimetric augmentation. Single-image radar resections were performed for digital imagery from the SAR580 airborne system and SIR-B satellite system using the SMART radargrammetric software system. Map-to-image correspondence was applied to each data set to produce registered map overlays. The approach has important implications for both interactive and automated analysis of SAR data and is well-suited for use in areas of high relief.

IMPLEMENTATION OF MAP-TO-IMAGE-CORRESPONDENCE FOR SYNTHETIC APERTURE RADAR IMAGE ANALYSIS

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ABSTRACT

Radargrammetric techniques, developed to support stereo mensuration and data capture from synthetic aperture radar (SAR) imagery, have been extended to enable map-to-image correspondence for computer-assisted radar image analysis. This mechanism projects existing digital map data into the image space of a new SAR image rigorously accounting for the sensor imaging geometry and terrain configuration.

Prerequisites for SAR map-to-image correspondence include (1) an analytical sensor model, (2) recovery of the image acquisition parameters and (3) three-dimensional (3d) digital map data. Analytical radar mapping techniques address the first two issues. Suitable 3d planimetric map data can be compiled directly from stereo photography using analytical plotters or indirectly using elevation data interpolated from digital elevation models to augment conventional two-dimensional map data derived from manuscripts.

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INTRODUCTION

There is growing world-wide interest in the development of synthetic aperture radar (SAR) systems for the acquisition of remote sensing data independent of ambient illumination and weather. SAR is especially attractive for earth resources tasks such as monitoring agricultural crops, snow pack and sea ice that require timely, repetitive coverage. Advances in microelectronics are leading to airborne and spaceborne SAR systems characterized by improved performance with greatly reduced size and cost.

Development of geographic information system (GIS) technology has led to considerable interest in integrating remote sensing imagery with digital map data. It is recognized that analysis of timely imagery is critical to maintaining and updating a GIS. Further, it is hypothesized that a priori terrain knowledge resident in a GIS should be of considerable value in the analysis of new imagery. Many efforts have focused on the exploitation of digital Landsat multispectral data within geographic information systems. Some researchers have also emphasized the integration of mapping photography with digital map data (Lukes, 1981 and McKeown, 1984). The general concept of interfacing remote sensing imagery with previously extracted digital map data maintained in a GIS is comprehensive. It extends naturally to the task of exploiting repetitive SAR coverage.

Previously, radar mapping techniques have been pursued with the primary objective of performing initial topographic mapping from stereo radar data. This has been of interest for areas dominated by cloud cover and adverse weather such as the Equatorial belt, the high latitudes and, more recently, the planet Venus. Modern analytical plotter technology has enabled consideration of cost-effective solutions to the radar mapping problem.

In some sense, our research has been stimulated by each of these trends. Extraction of digital spatial data from repetitive SAR coverage for storage in a GIS represents a logical approach to processing the anticipated volume of SAR data. Map-to-image correspondence, based on concepts developed for radar mapping, provides critical tools to support analysis of SAR imagery based on exploitation of previously acquired digital map data.

SAR MAP-TO-IMAGE CORRESPONDENCE

The objective of this study was to implement modular radargrammetric procedures to project digital map data into the image space of synthetic aperture radar data and to demonstrate this capability on SAR imagery acquired from both airborne and spaceborne platforms. Several conditions must be satisfied to support rigorous map-to-image correspondence.

Sensor Model

Mapping and reconnaissance imaging systems have been developed to sense and record two-dimensional images of the three-dimensional world based on diverse physical principles and imaging conditions. For a given type of sensor, rigorous map-to-image correspondence is feasible only if a mathematical model has been implemented to analytically characterize the imaging geometry of the sensor based on the position and orientation of the sensor.

Radar imaging geometry, described by the well-known range equations, is fundamentally different than the perspective imaging geometry of optical systems. Mathematical formulation of radar imaging conditions for specific types of systems, however, provides the basis for predicting image locations corresponding to terrestrial objects, a process analogous to the collinearity condition for optical systems.

Recovery of Image Acquisition Parameters

Recovery of image acquisition parameters, often described as triangulation, is a standard problem in the implementation of either a photogrammetric or radargrammetric system. Early efforts in radar mapping, as described by Norvelle (1972), were conducted on specialized military systems such as the AS-11 analytical plotter. More recent initiatives have been based on the extension of radargrammetric capabilities to commercial analytical plotters as described by Autometric (1982) for the APPS-IV, and Raggam and Leberl (1984) for the Kern DSR-1.

Recovery of acquisition parameters through single image resection and multi-image block adjustment has been demonstrated independently on several systems as a precursor to stereo radar map compilation. For our purposes, the availability of image acquisition parameters is necessary and sufficient to enable map-to-image correspondence for a terrestrial object described by three-dimensional ground coordinates.

Three-Dimensional Digital Map Data

Generation, management and exploitation of digital map data is the major focus of mapping research and development in the world today. In general, digital mapping activities are organized around the production and/or use of two classes of products: digital elevation data or digital elevation models (DEM) and digital planimetric data. Although digital elevation data is inherently three-dimensional, most planimetric data has been digitized from two-dimensional manuscripts. The requirement of three-dimensional digital map data necessary for map-to-image correspondence may be addressed in several ways.

Planimetric Augmentation. Two-dimensional (2d) planimetric data can be converted to three-dimensional (3d) data if a corresponding digital elevation model (DEM) is available. For every 2d coordinate pair in the data set, a corresponding elevation value is interpolated from the DEM to create a 3d coordinate triplet.

Photogrammetric Data Capture. Direct data capture of digital 3d map data from stereoscopic aerial photography using an analytical plotter as a 3d digitizer was demonstrated in the CAPIR program (Lukes, 1981). This approach maximizes metric accuracy and produces 3d planimetric data directly.

Radargrammetric Data Capture. With radargrammetric software such as SMART, it is now feasible to consider mapping directly from stereo SAR imagery using an analytical plotter. This process generates 3d ground coordinates which can be integrated into a digital mapping system.

CASE STUDY -- FREIBURG, WEST GERMANY

The concept of SAR map-to-image correspondence has been demonstrated in a case study conducted at the Institute for Image Processing and

Computer Graphics. The testsite covers an area of 5.5 by 10.0 kilometers which lies west of the city of Freiburg and east of the Rhine River in southwestern West Germany. The area is characterized by diverse land use and is used by many remote sensing research programs.

SAR Imagery

Synthetic aperture radar imagery over the Freiburg testsite has been obtained during several experiments. In 1981, the SAR580 Campaign made an extensive set of SAR acquisitions over the testsite which were digitally processed by DFVLR. In this study, a digital X-band image (3858 pixels by 2255 lines) acquired on 7 July 1981 with a nominal ground resolution of 3 meters was processed to provide an example of airborne SAR imagery. In 1984, the site was imaged from space during the Shuttle Imaging Radar Experiment (SIR-B). A digital image from this data set obtained on 10 October 1984 with a nominal resolution of 25 meters was processed as an example of spaceborne SAR imagery.

Radargrammetric Processing

In all cases, the SMART radargrammetric software was adapted to recover acquisition parameters of the digital images. Ground control was assembled from topographic maps, approximate flight profiles were inferred from incomplete collateral information and inspection of the imagery, image coordinates were measured interactively using the DIBAG digital image processing system and a single image SAR resection was performed.

Digital Map Data

Selected map overlays were compiled from standard 1:50,000 topographic maps and digitized using the DESBOD system. These were transformed to a three-dimensional representation through the process of planimetric augmentation using digital elevation model (20 meter grid spacing).

A transportation map was compiled incorporating roads (autobahn, primary roads, secondary roads), railroads, canals and powerlines. A graphic plot of the transportation map data is presented in Figure 1. A second data set is assembled for landcover classified in 14 categories as shown in Figure 2.

Annotated SAR Imagery via Map-to-Image Correspondence

For each of the four cases in this data set, the image-space overlays were generated via SAR map-to-image correspondence and displayed on the DIBAG digital image processing system. Recorded images with the map data overlays on the SAR images are presented for transportation in Figure 3 and landcover in Figure 4. In each case, use of radargrammetric procedures provides the desired correspondence between image and map data.

DISCUSSION

This example was inspired by the problem of cartographic change detection for map revision. It illustrates the significance of the planimetric augmentation concept as a means of processing existing 2d digital map data. Other earth resources tasks requiring frequent

monitoring are ideal canditates for repetitive SAR coverage. For such applications, SAR map-to-image correspondence could be exploited in the following fashion.

For the geographic area of interest, a 3d digital map data is constructed from stereo metric photography using an analytical plotter. Depending on the application, source material could include small-scale space photography from the NASA Large Format Camera and the ESA Spacelab Metric Camera, or larger scale aerial photography from conventional sources. Task-specific feature maps would be compiled; crop classification studies, for example, would require delineation of individual agricultural fields in selected test areas. A separate data base of distinctive SAR-identifiable ground control points (GCP) would be assembled to support subsequent SAR triangulation.

Routine exploitation of repetitive SAR imagery would require recovery of the image acquisition parameters based on measurement and processing of the SAR GCP. Selected digital map data would then be displayed as overlays on the new imagery using map-to-image correspondence. Based on analysis of the imagery, the data base would be updated. In applications such as crop classification, entry of attribute data interpreted for each specified map feature will be sufficient. Other problems, such as sea ice mapping, will require use of additional radar mapping procedures to enter new positional information into the data base.

This concept has been described in the context of interactive image exploitation where SAR map-to-image correspondence is used to register existing map data to a new radar image to aid the human analyst. This analytical procedure also supports map-guided scene analysis where the objective is automated interpretation of the imagery. While this image understanding research is still in its infancy, exploitation of a priori map information appears to hold significant promise to constrain autonomous search and analysis tasks. Areas of research opportunity have been outlined by McKeown and Lukes (1984) and initial research results in rule-based scene analysis of digital aerial photography in the MAPS/SPAM system have been reported by McKeown, Harvey and McDermott (1985).

Automation of the image triangulation task also holds promise. When reasonable estimates of the image acquisition parameters are available, the approximate location of GCP can be predicted to guide automated matching techniques. A sufficient number of successful matches permits automated determination of precise acquisition parameters.

CONCLUSIONS

The use of map-to-image correspondence to support the analysis of synthetic aperture radar imagery has been demonstrated for both airborne and spaceborne SAR data. Radargrammetric techniques, developed to solve the geometric aspects of the radar mapping problem, can also play an important role in SAR image exploitation.

The three prerequisites for SAR map-to-image correspondence -- a rigorous sensor model, recovery of acquisition parameters, and three-dimensional digital map data -- can be satisfied for existing data through use of novel procedures and advanced compilation techniques.

Analytical procedures, developed for the current generation of analytical plotter instrumentation to process film-based (hardcopy) imagery,

extend naturally to systems designed to process digital (softcopy) imagery. Much further work is warranted to explore the opportunities presented by the integration of digital map and image data via map-to-image correspondence.

ACKNOWLEDGEMENTS

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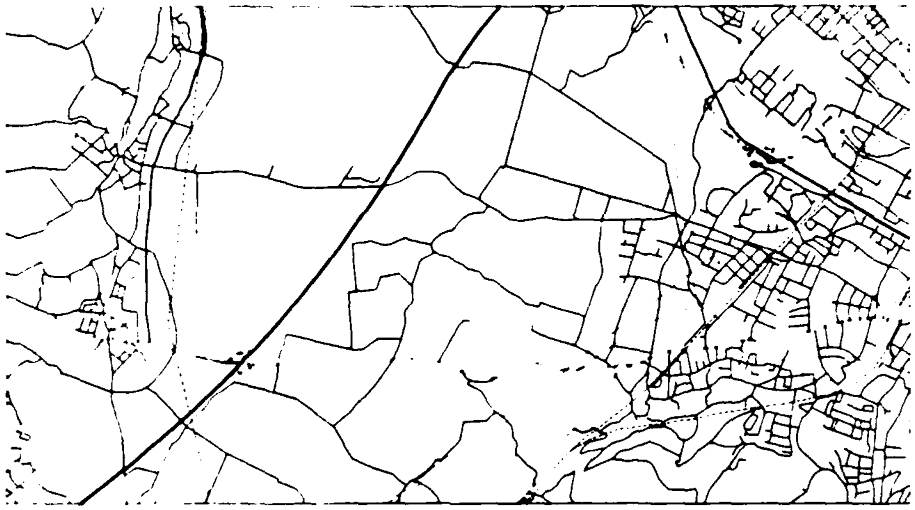

Figure 1. Testsite Transportation Data. Linear features representing the transportation network for the Freiburg testsite were compiled from 1:50,000 topographic maps. Delineated features include autobahn, primary (national) roads, secondary roads, railroads, canals and powerlines.

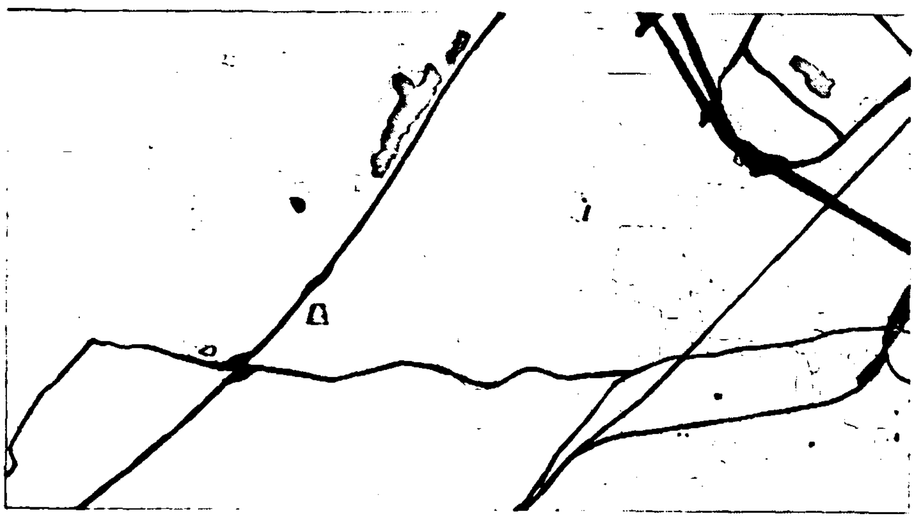

Figure 2. Testsite Landcover Data. Areal features describing Freiburg testsite landcover were compiled from 1:50,000 topographic maps. Mapped features include deciduous and mixed forest, marsh, meadow/pasture, vineyard, garden, built-up areas with or without gardens, sports fields, cemetery, mine, right-of-way, open water and undefined areas (typically agricultural fields).

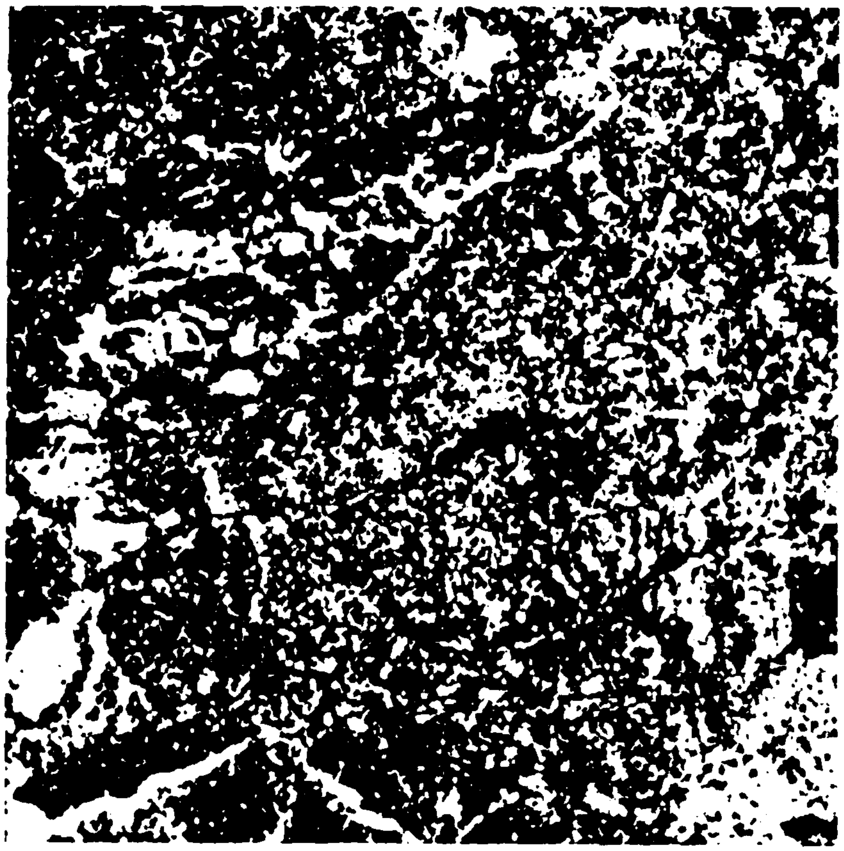

Figure 3. Testsite transportation network projected to overlay onto SAR imagery via map-to-image correspondence: above, airborne SAR580 image; below, SIR-B image acquired from the Space Shuttle.

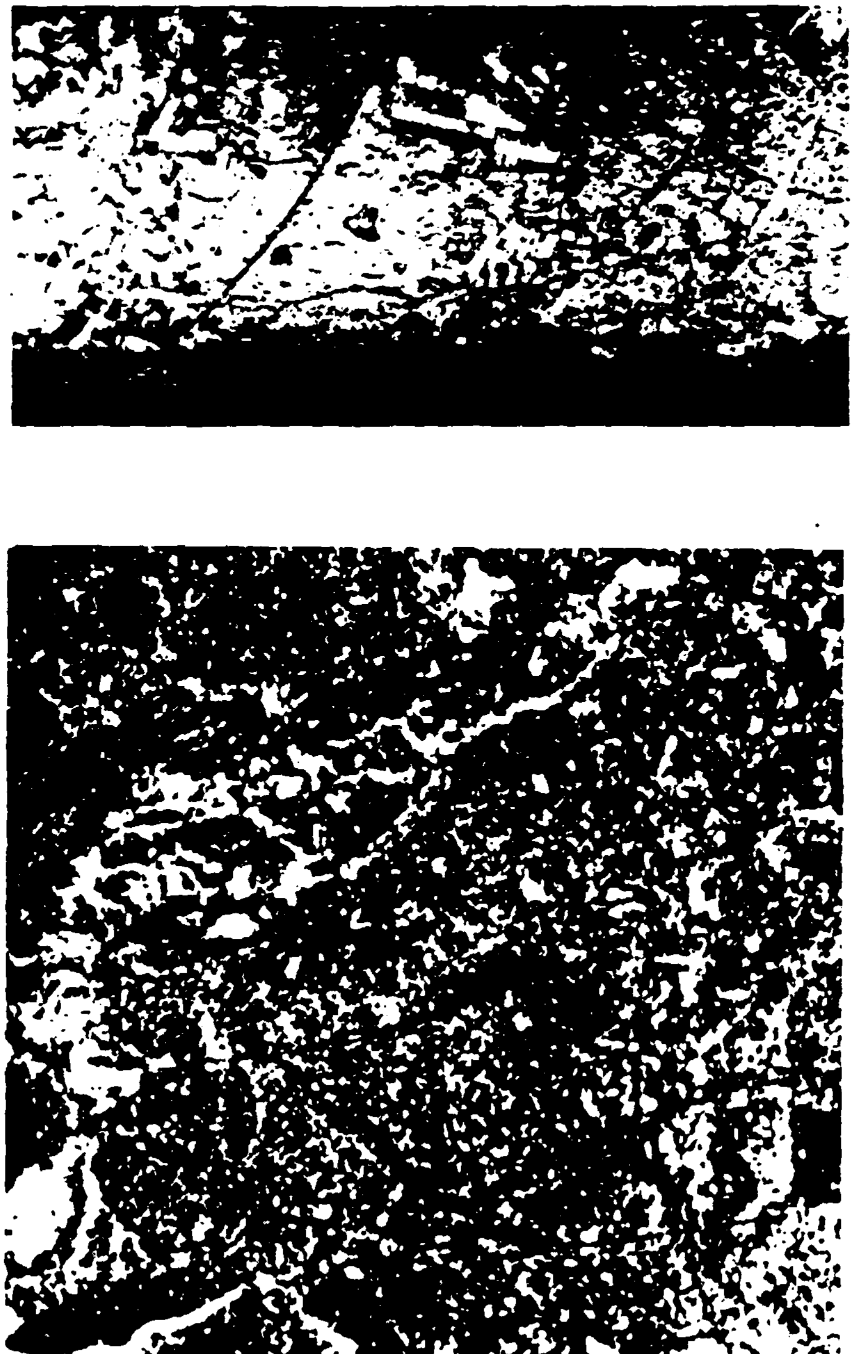

Figure 4. Testsite landcover data projected to overlay SAR imagery via map-to-image correspondence: above, airborne SAR580 image; below SIR-B image acquired from the Space Shuttle.

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